Sveriges lantbruksuniversitet
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Variation in neonate roe deer home range size

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Master's thesis
Grimsö 2017

Independent project/Degree project / SLU, Department of Ecology 2017:2

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Credits: 45
Level: A2E
Course title: Independent project in Biology - Master's thesis
Course code: EX0596

Place of publication: Grimsö
Year of publication: 2017
Cover picture: Charlotte Öhman
Title of series: Independent project/Degree project / SLU, Department of Ecology
Part no: 2017:2
Online publication: http://stud.epsilon.slu.se

Keywords: home range size, roe deer, *Capreolus capreolus*, neonate, fawn, roe deer density, fox density, agricultural land, Sweden, movement, body mass.

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Abstract

Home range determinants have been well-studied in many species, as is the case for adult roe deer. However, drivers of neonate roe deer home range size have not been covered in previous research. Earlier studies demonstrate a negative relationship between both increasing food availability and population density on adult roe deer home range size. Because neonate roe deer are highly dependent of their mothers during the first weeks of life, I expected that fawn home range size would be affected similarly by similar factors. It was also predicted that home range size and daily movements would be affected by fox density, temperature, year, fawn age, birth weight, sex, tick burden, and some mother qualities. Based on 91 radio-collared neonate roe deer (118 in movement analysis) and 12 adult females (14 in movement analysis) – comprising of 17 complete female-fawn relationships (23 in movement analysis), in two different study areas in south central and eastern Sweden, I show that, as expected, home range sizes of fawns and females were positively correlated. Moreover, neonate home range size and movements varied significantly between areas. The difference between the areas was partly explained by contrasting densities of which increasing abundances of both fox and roe deer caused smaller home ranges and shorter movements. Results are attributed to that both the increasing densities of roe deer and fox cause social constraints and avoidance behaviour, consequently decreasing both movements and home range size. This study is the first to determine the main drivers of neonate home range size and provides new knowledge of neonate roe deer spatial use encouraging for future studies based on these findings.

Populärvetenskaplig sammanfattning

Djurs vistelseområden eller hemområden är väl undersökta inom forskning och själva termen ”hemområde” är vida känd som definitionen av ett område där ett djur rör sig för att få utlopp för sina dagliga behov. Detta kan vara allt från att hitta mat eller möjligheten att gömma sig undan rovdjur. I dag vet man till stor del vad som påverkar vuxna rådjurs val av hemområde och hur stora de blir. Däremot är det inte tidigare kartlagt vad som formar och påverkar de nyfödda kidens hemområde. Man vet mycket om vad som påverkar kidens överlevnad i olika miljöer och områden, när antalet rådjur varierar samt i relation till mammornas (getternas) egenskaper. Denna studies syfte har därför varit att täcka detta outforskade vetenskapsområde och besvara frågan: Vad är det som påverkar hemområdesstorleken hos små rådjurskid? Även faktorer som påverkar kidens dagliga förflyttning undersöktes samt om denna förflyttning har något samband med hemområdesstorleken. Studien genomfördes genom att fånga och märka nästan nyfödda rådjurskid med små lätta (70g) radiosändarhalsband som tillät radiopejling.

Det var väntat att det skulle finnas ett samband mellan getens och kidets hemområdesstorlek och dagliga förflyttning. Det sambandet och eftersom vuxna rådjurs hemområden är mindre i områden med stort antal rådjur och stor mängd åkermark, antogs även att kidens hemområden skulle visa samma mönster. Det förväntades även att rådjurskids hemområden skulle vara mindre och daglig förflyttning skulle vara kortare med områden av hög rådjurstäthet på grund av ett undvikande beteende från rådjurens sida. Andra faktorer som undersöktes var studieområde, täthet av räv, år, kidets ålder, moderns ålder, kidets vikt, moderns vikt, temperatur, kön, mängd fästingar funna på kid samt längd förflyttning av modern.

Som förväntat var antalet rävar och rådjur samt getens hemområde de tre faktorer som hade störst påverkan på kidens hemområden. Studien antyder också att ju varmare sommarväder desto mindre hemområden får kiden, troligen för att dessa rör sig mindre och vill undvika överhettning. Det var även en skillnad mellan de två studieområdena. Det område som hade de minsta hemområdena hade även den största mängden rådjur och rävar och högre temperaturer, vilket sammantaget förklarar mycket av denna skillnad i hemområdesstorlek. Vuxna rådjur undviker varandra och speciellt precis efter kidens födsel vilket kan förklara varför mängden rådjur har en påverkan. Dessa resultat är nya i forskningsområdet då man för första gången kan få svar på vilka faktorer som påverkar rådjurskidens hemområdesstorlek och kan vara ett värdefullt bidrag till framtida forskning.

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1 Introduction

A home range is defined as a "*part of an animal's cognitive map of its environment that it chooses to keep updated*", and it has a dynamic shape and size determined by multiple extrinsic and intrinsic factors (Powell & Mitchell, 2012). An early definition by Burt (1943) stated that it is an area where an animal roams to search for food. Today the definition is revised and defined as an area where the performance of an individual's daily activities and needs is made possible, such as foraging needs and predator avoidance (Powell & Mitchell, 2012). What a home range for an individual is depends on various factors. An individual home range may change between different locations and vary in size throughout life (Powell & Mitchell, 2012). Different life stages of an animal will generate a different home range since these stages differ in needs. Newborns are generally more susceptible to environmental conditions and suffer a higher risk of mortality (Nelson & Woolf, 1987; Gaillard et al., 1997; Jarnemo et al., 2004) meaning that survival is the most important focus; while adults may instead have stronger focus on reproduction and adjust their home ranges in relation to potential partners (Dahle & Swenson, 2003). Home ranges of adult roe deer (*Capreolus capreolus*) have been well-studied and some known effects are that these home ranges vary in relation to resource abundance, intraspecific density, and season, depending on the needs of the individual (Kjellander et al., 2004; Panzacchi et al., 2009; Morellet et al., 2013). Less is known about the home ranges of neonate roe deer. Most studies have focused on fawn survival, movements, and mother interactions (Gaillard et al., 1998; Linnell & Andersen, 1998; Jarnemo, 2004; Jarnemo & Liberg, 2005; Panzacchi et al., 2009; Panzacchi et al., 2010). This means that, to my knowledge, neonate roe deer home range size is an unexplored topic. Therefore, the focus of this study is to determine the main drivers of neonate roe deer home range size in relation to its daily movements and other extrinsic and intrinsic factors.

1.1 Home range determinants of roe deer

Home range size is generally the outcome of trade-offs between nutritional needs, energy requirements, and predation risk. In particular, resource availability is commonly a determinant of home range size in several different mammal species, such as chipmunks (*Tamias striatus*), grizzly bear (*Ursus arctos*), and red deer (*Cervus elaphus*, Mares et al., 1982; Edwards et al., 2013; Adam et al., 2015). Since roe deer are selective browsers consistently choosing high quality forage when available (Moser et al., 2006), higher abundances of high quality food consequently decrease home range size, likely to avoid unnecessary energy expenditure (Panzacchi et al., 2009; Saïd et al., 2009; Nordström, 2010; Morellet et al., 2013). For example, home ranges in less productive areas were shown to be twice as big compared to areas of higher productivity (Kjellander et al., 2004). Choice of feeding patch is also a trade-off between quality and quantity. This means that forage species with the highest nutritional quality may not always be chosen if the patch is small (Moser et al., 2006). The roe deer is therefore also considered a habitat generalist by displaying a plastic feeding behaviour and chose sites with higher abundance of low quality forage when high quality resources are scarce (Abbas et al., 2011). This means that roe deer can benefit from fragmentation because they can shift between forage sites when necessary (Abbas et al., 2011). Roe deer also spend much time near habitat edges, indicating that different habitats can provide different types of resources preferential to them (Tufto et al., 1996).

Because resource availability commonly varies among seasons, seasonal variations in home range size are also expected in roe deer. Indeed, studies on adult roe deer also show that quality of forage and season are valid predictors of home range size (Saïd et al., 2009; Morellet et al., 2013). This pattern is clearly a consequence of roe deer belonging to the income breeder style (Jönsson, 1997), i.e. a species that relies on current food availability to maximize reproduction and lactation to sustain their fawns (Andersen et al., 2000). However, such seasonal variations observed in home range size also depend on local population density. Indeed, increasing densities of roe deer can influence their spatial distribution. In two long-term studies of roe deer in Sweden and France, home range size of adult roe deer showed to have a strong negative relationship with intraspecific density (Kjellander et al., 2004). When roe deer density was low, home range size was more influenced by seasonality; with larger size differences between winter and summer, than during high roe deer density (Kjellander et al., 2004). A study conducted with data spanning across Europe on a latitudinal gradient showed that home range size of roe deer varied on a monthly and weekly scale with a minimum size during spring and maximum during winter (Morellet et al., 2013). These patterns were related to variations in temperature and day length, where a decreasing home range size was

related to lower temperatures for both northern (North 61°) and southern locations (North 41°); with a reversed pattern found in the middle regions (Morellet et al., 2013). Climatic fluctuations in precipitation and temperature were also shown to have negative effects of home range sizes (Börger et al., 2006b).

In a comparative analysis on ruminants, including roe deer, it was found that body mass was a good predictor of home range size; and the relationship was even more pronounced during the summer season for the browser group (Mysterud et al., 2001). However, body mass was not a significant predictor of home range size in a study by Saïd et al. (2009). The previously mentioned study found that resource abundance influenced the home range size of adult female roe deer, and argue for that body mass is probably not a good predictor alone. They continue explaining that home range size is likely more adjusted to fluctuating factors such as food availability. A large female is, however, argued to have the advantage of relatively lower energy expenditure per reproductive event and according to the income breeder strategy, roe deer will maximize litter size accordingly (Andersen et al., 2000). The mother may affect its fawn in various ways. Gaillard et al. (1998) show that family effects on sibling survival also exist in absence of predators, concluding that sibling fawns inherit their mother's characteristics (Gaillard et al., 1998).

1.2 The neonate roe deer period: movement and home range in relation to predation risk

During fawning season, roe deer females with fawns have larger home ranges than females without, which is explained by mothers needing larger areas to forage enough to support energetic costs of lactation (Tufto et al., 1996). The female roe deer have a synchronized birth strategy with peak birth period around mid-May to early June in parts of Europe (Gaillard et al., 1993; Aanes & Andersen, 1996; Linnell & Andersen, 1998; Jarnemo et al., 2004; Plard et al., 2013). The synchronized birth strategy is suggested to be linked with vegetation development and spring flush and again in line with the income breeder strategy (Plard et al., 2014). This strategy also likely favours fawn survival, since fawns born outside the birth peak period suffered higher risk of predation (Jarnemo et al., 2004). However, studies are not unanimous in this conclusion (Linnell & Andersen, 1998). An important cause of neonate roe deer mortality during this time is predation from red foxes (*Vulpes vulpes*, Jarnemo, 2004; Jarnemo & Liberg, 2005; Panzacchi et al., 2009).

The roe deer is a typical hider species where the fawns hide in a bed site of their own choice generally within 20 m (pers. comm. A. Jarnemo, 15 January 2017) from a location chosen by the female (Van Moorter et al., 2009). The fawn then receives

visits from the female around every seventh hour (Espmark, 1969). The strategy of hiding is a method for neonate roe deer to avoid predators (Linnell & Andersen, 1998). A smaller fawn home range and decreasing movements within a forest-dominated area in Norway have shown to increase predation risk and predictability of bed site locations (Panzacchi et al., 2009). Fawns are more active in forest areas than in croplands and the amount of activity increases with age (Panzacchi et al., 2010). The increasing survival with more movement in forests is probably related to the availability of hiding places. There may be hiding places of lesser quality in forests and it might therefore be easier to find for a predator compared to a crop field where it is difficult to distinguish one location from another (Linnell et al., 1999; Van Moorter et al., 2009). It is also mainly related to the increasing movement of the female whose resources in forests are distributed over larger areas than in croplands (Jarnemo, 2004).

The lower activity levels in agricultural areas is likely because of female visibility being at its maximum here (Panzacchi et al., 2010), and she may act as a visual cue for predators resulting in higher risk of exposure of her fawn's location. However, when the female is close enough, she can also successfully protect her fawns from small predators. For example, Jarnemo (2004b) found that, when the female was in the vicinity, she successfully deterred the fox under the attack in 90 per cent of the cases. Females are also closer to their fawns in croplands than in other habitats pointing out a possibility to adjust the distance according to habitat (Panzacchi et al., 2010). This trend is presumably a behavioural adjustment by the females to be able to defend its young from predators (Panzacchi et al., 2010).

1.3 Aim

This study covers neonate roe deer home ranges during their hiding phase, i.e. between birth and two months of age, when mortality is high (Aanes & Andersen, 1996; Jarnemo et al., 2004). The study also investigates movement within the home range using the measure of daily average movement (DAM). Due to the high mortality and its previously mentioned connection with amount of activity and movement within different habitats (Panzacchi et al., 2010), the daily average movement will provide even further information about neonate roe deer space use. The study aims to test the relationship between movement and home range size and to compare these two metrics with different types of extrinsic and intrinsic factors, possibly affecting spatial use in two neonate roe deer populations. The aim will be achieved by answering the following questions and test their associated predictions.

1) Is there a significant difference of fawn home range size and DAM between two study areas?

I hypothesize to find smaller home ranges in one study area (Bogesund) than the other (Grimsö) due to 1) the higher roe deer density that results in less space to inhabit, and 2) the higher proportion of agricultural areas for the mothers available in Bogesund (Kjellander et al., 2004; Panzacchi et al., 2009; Nordström 2010; Morellet et al., 2013). Due to the larger proportion of agricultural areas, I expect that there will be decreasing daily average movement due to it being favourable for survival in these habitats (Panzacchi et al., 2009).

2) Is neonate roe deer home range size and DAM influenced by their mothers' qualities and spatial behaviour such as home range size, body mass, and age?

So-called family effects between siblings have been demonstrated, possibly indicating strong effects of inheritance (Gaillard et al., 1998). Therefore, I expect that a fawn's home range size will be related to its mother's. For example, generally there is a habitat-dependent distance between a fawn and a mother and because food availability is considered primarily (Panzacchi et al., 2010). Therefore, females must move over large areas to sustain themselves due to low food availability and fawns will do the same. Due to the expected connection between movement and home range size, I also expect that the daily movements of the fawn will have a positive relationship with its mother's movement. Assuming that the first two mother attribute predictions are true, I expect that home range size and daily average movement of fawns will be related to their mother's body mass because large females have larger home ranges (Mysterud et al., 2001), suggesting a relationship between the two. Moreover, I expect that by increasing female age both neonate home range size and daily movements will decrease. Indeed, experience may lead to a better balance between energy expenditure and nutritional quality and risk, and may thus change a behaviour in a long-lived species. For example, by giving birth at an earlier date with increasing age (Plard et al., 2014). Other behaviours can be affected as well, for example, adult female white-tailed deer (*Odocoileus virginianus*) have larger home range size and fawn-rearing success with increasing age (Ozoga & Verme, 1986). In roe deer, adult female age has previously been shown to have a negative effect on their own home range size (Saïd et al., 2009).

3) Are neonate roe deer home range size and DAM influenced by environmental factors such as roe deer population density, predator density, or by the proportion of agricultural land?

First, since I expect a correlation between female and neonate home range sizes and movements, I also expect that the determinants previously discovered affecting female home range size will similarly affect neonate home range size. Since adult roe deer home ranges decrease in size with increasing food availability and because agricultural areas represent high-quality resources for roe deer (Panzacchi et al., 2009; Nordström 2010; Morellet et al., 2013), I expect a decreasing size with an increasing proportion of cropland. Also, fawns in cropland habitat move less than those in forests (Panzacchi et al., 2009), which is also expected to lead to a smaller home range. Moreover, I expect that fawns will have smaller home ranges in areas of high roe deer density, since this relationship have been found in adult roe deer (Kjellander et al., 2004). They will also move less due to the restricted movements of individual roe deer in roe deer dense areas, which are hypothesized to be due to social constraints (Pettorelli et al., 2003). Finally, I predict that decreasing daily average movements and home range size will decrease with increasing fox density since hiding is a low-movement strategy to avoid predators (Linnell & Andersen, 1998).

4) Do neonate roe deer home range size and DAM relate to fluctuating climatic factors such as changes in temperature and precipitation?

A change in home range size, in June due to temperature and amount of precipitation is expected because of previously shown effects on home ranges of these factors (Gaillard et al., 1997; Börger et al., 2006; Raganella-Pelliccioni et al., 2006; Morellet et al., 2013). It is expected that increasing mean temperature in June will lead to an increased neonate roe deer home range size and daily movements since thermoregulation and light penetration is important and hypothermia is a common cause of death for fawns (Andersen & Linnell, 1998; Jarnemo, 2004; Van Moorter et al., 2009). Further, an increasing mean amount of precipitation in June is expected to decrease home range size and movements to avoid hypothermia and due to the increase in potential food availability (Plard et al., 2015). Since roe deer are income breeders and need to fill their energetic requirements regardless of environmental variation (Andersen et al., 2000; Morellet et al., 2013), behavioural responses are expected to be related to between-year variations as well.

5) Is there a gender difference in the size of a home range and the DAM for fawns?

Aanes and Andersen (1996) concluded that an increased proportion of agricultural land resulted in increased mortality in male neonates. I thus suspect that males will have smaller home ranges due to the high quality of the agricultural area as a hiding

habitat, and increasing movements compared to female fawns, when controlling for the proportion of agricultural area, since increasing movement in agricultural areas relates to decreased survival (Panzacchi et al., 2009).

6) Are there intrinsic effects of fawn quality determining neonate home range size and movements, such as birth weight, age, and tick burden?

It is expected that an increasing fawn weight will increase home range size and consequently longer movements because of larger mothers' ability to provide more food to their fawns (Andersen et al., 2000), and because of the allometric relationship between body mass and home range size of browsers (Mysterud et al., 2001). More concentrated use of an area in red deer and high density of cervids is related to increasing tick density (Handeland et al., 2013; Qviller et al., 2016). Since smaller adult home ranges are connected to an increasing population density (Kjellander et al., 2004), this leads to the assumptions that fawns with smaller home ranges (i.e. moving within a more concentrated area) and subsequently shorter travelled distance per day, may be under larger tick pressure. Lastly, since distance between female and fawn increase with age (Panzacchi et al., 2010), I hypothesize that both home ranges and DAM will increase with increasing fawn age.

2 Materials and methods

2.1 Study site

The study was carried out in two different areas of Sweden on approximately on the same latitude; Grimsö Wildlife Research Area 59°72´87´´N, 15°47´20´´W and Bogesund 59°39´33´´N, 18°28´45´´W. Grimsö is located south central in Sweden and the research area covers 13.5 km^2. Land use in the area is mainly high production forest (74 %); bogs, fens, and rocks comes in second (18 %). The rest constitute of lakes and rivers (5 %), and a small percentage of agricultural area (3 %). The research area is situated 50 - 180 m above sea level and had a mean annual precipitation of 739 mm between 1961 - 2014 (SMHI, 2016b). A few people live in the area and there are only three larger farms which contribute to the coverage of agricultural area. The forests in the area mainly consists of conifer trees and dominating species are Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*). The deciduous trees in the area represent a minority but most common is birch (*Betula* spp.). Small shrubs as bilberry (*Vaccinium myrtillus*), heather (*Calluna vulgaris*), and lingonberry (*Vaccinium vitis-idaea*) are common plants in the understory. In more open areas such as clear cuts, the forb fire weed is common which is an important food source for roe deer (Cederlund & Nyström, 1981).

Bogesund research area is situated in east central Sweden in the inner part of the Stockholm archipelago, situated on a mainland peninsula northeast of the inner city and covers 1.2 km^2. Compared to Grimsö, Bogesund has a considerable larger proportion of agricultural land with a coverage of 25 per cent. Approximately 65 per cent is forested and the remaining 10 per cent is covered by bogs or represent more rocky areas. Common trees in the forested habitat are, as in Grimsö, Norway spruce, Scots pine but deciduous trees are more common than in Grimsö, such as birch, oak (*Quercus robur*), linden (*Tilia cordata*), and willow (*Salix* spp.). Ground vegetation excluding lichen and mosses covered more ground in Bogesund than in

Grimsö in 1994; whereas dwarf shrubs had a higher coverage in Grimsö (Guillet, 1994 in Guillet, 1996). Other open areas comprise of meadows and young forest plantations. Common ground vegetation is bilberry and abundant herbaceous vegetation. Common crops are oilseed rape, oats, and wheat. The rest of the fields are pastures or hay and silage production for livestock or horses. Mean annual precipitation rates was 591 mm between 1961 - 2014 (SMHI, 2016b).

2.2 Data collection

Between 2013 - 2016, 118 neonate roe deer were captured and equipped with VHF-collars (Followit, Lindesberg, Sweden) with a drop-off function and an expanding collar designed to wear, brake layer by layer, and gradually expand. The collars had a life span of around 1.5 years. The methods for catching the fawns were conducted in various ways. Neonate roe deer hide and stay still when approached in the vegetation which makes it easy to pick them up by hand. This method was done when possible. Otherwise, a hoop-net was used for some individuals and occasions. Methods used to find fawns were mostly through observations of marked or unmarked adult females, observation of GPS-cluster in ArcGIS (when the female roe deer had GPS-collars), or following a VHF-marked female in real time. Data sampled during fawn capture and used in the analyses consisted of weight, number of ticks, sibling and mother ID (if marked), and sex. Behavioural data and state of the umbilical cord was also recorded (see "Date of birth").

The fawns were recaptured one or more times when possible and were located once a day (with some exceptions due to technical errors) throughout the summer period between May and August. VHF-locations were usually based on three bearings, however, when signals were weak, only two bearings were used. Repeated locations through triangulation of deer has proven to be useful in determining total home range area in previous research (Heezen & Tester, 1967). This sampling strategy resulted in multiple locations of the fawns during summer. In average 39 (min 27, max 60) locations per fawn were recorded up to the age of 62 days. Of the 118 captured fawn, 91 fawns had enough positions (>27) to be included in the subsequent home range analysis.

Adult females were equipped either with a VHF-collar (151 MHz, Followit, Sweden, at Bogesund) or a GPS-collar (Vectronic Aerospace GmbH, Berlin, Germany, model Pro-light). Total number of included females was 14 unique individuals in the daily average movement analysis and 12 in the home ranges analysis.

2.3 Outlier exclusion

GPS-positions from females with a positional dilution of precision (PDOP) value over 10 were excluded. PDOP is a measure of quality of GPS-locations, with lower values indicating a higher accuracy of the generated location (D'eon & Delparte, 2005). Using a lower cut could have introduced unnecessary bias in the data by removing too large part of all GPS positions; whereas a cut at 10 removed major outliers while avoiding the exclusion of a too large part of the original dataset (D'eon & Delparte, 2005).

Outliers in fawn data were excluded by calculating a barycenter of the home range with only using points that had a lower total distance than 3000 meter between the previous and the following point. This was done because the barycenter with all positions was distorted by some error coordinates. A study by Panzacchi et al. (2009) showed an average daily movement in one of their areas of 530 m (SD 450 m). The two study areas in Panzacchi et al. (2009) were situated in Norway and had a similar habitat composition as Grimsö and Bogesund. Maximum possible distance of these numbers was approximately 1000 m (530m+450m); consequently, a cut of 1500 m was used between the barycenter and the positions in this project. 50 % of the distance was added to the 1000 m as a buffer to not make unnecessary assumptions, since the cut in this study was made from the barycenter and not between positions. After exclusion of major outliers, a new barycenter was created from the new dataset and here a cut was made with 1000 m from the barycenter according to the maximum travelled distance in Panzacchi et al. (2009).

Trajectories were visually analysed, and positions which were excluded by distance but had consecutive points in the same area were included manually afterwards. These could not be assumed to be outliers due to the consecutive location pattern. Positions which were autocorrelated were removed since results can be biased if these are not independent from each other (Hansteen et al., 1997). A cut was made with a minimum time difference of seven hours between positions, which was similar to the mean time difference between suckling events in roe deer that have been shown to be six hours and 47 minutes (Espmark, 1969). This meant that the likelihood of the fawn having moved between locations was high.

2.4 Assessment of home range size and daily movement

2.4.1 Home range size

Generally, the number of positions used to estimate home ranges are of minimum 30 (Seaman et al., 1999; Girard et al., 2002). However, many fawns were lost by this decision and using a cut of 27 generated a sufficiently larger dataset that justified including them. Because much more locations were available for GPS-collared females, for them I randomly selected one location per day during the fawn monitoring period (June-July).

For both fawns and does, estimations of individual home range size were conducted using the Kernel method (90 %) with an 80 % correction of h_{ref}. The Kernel method uses a bivariate probability density function to estimate home range size (Worton, 1989). Home ranges created with the MCP-method (Minimum Convex Polygon) have only been presented with effect sizes to display the extent of the actual fixes compared to the Kernel estimator, however they were not used in the statistical analysis since MCP calculates no probability of use (Nilsen et al., 2008). However, MCP has previously commonly been used in studies making the inclusion advantageous (Laver & Kelly, 2008). According to Kie et al. (2010), the standard smoothing parameter for Kernel home range estimation (h_{ref}) can sometimes over-buffer home ranges, but a correction of 80 % of the standard smoothing removes most of this error and seems suitable for many datasets. The correction of 80 % was added in this study to reduce this error and the home ranges were afterwards checked visually for biological relevance. Indeed, home ranges with the correction became more fragmented than without it. This confirms that by correcting the h_{ref} a more detailed home range is presented (Worton, 1989). The decision was to use the correction of 80 %. This was done since the home ranges were otherwise considerably larger and the differences between fawn VHF data's home ranges and GPS female data's home ranges were also larger.

Individual home range composition was estimated using ArcGIS (Version 10.4.0.5524 for Desktop, 1999-2015) with a background map from Swedish Mapping Cadastral and Land Registration Authority (SEPA, 2014). The estimated proportion of agricultural area per home range was performed in the same program by overlaying the background map with home ranges of both fawns and females and calculating the per cent coverage.

2.4.2 Daily movement

The daily movement (DAM) of fawns was estimated as meters moved per day. The movement was calculated as a daily average distance travelled. DAM was based on distances between several positions that had known times. A minimum of ten positions was used when choosing which individuals to include in the analysis. This minimum was applied since the relationship between DAM and number of VHF positions showed no significant correlation (R^2 = -0.008, p > 0.8), and a minimum amount of ten positions rendered a sufficiently larger sample size.

In the calculation, I included positions from both fawns and females that had a time difference of between 7 - 50 hours. The reason to not go over 50 hours was to capture positions that would give an average movement per day more accurately since a home range is limited, and positions with a time-difference over 50 hours were few. In the data, I could see that a longer time span between positions did not lead to an increased distance between two locations. Including such positions would therefore have skewed the distance travelled per day. However, for females with a VHF collar, a significant increase in distance could be seen with increasing time between positions, but the relationships had a low correlation coefficient (R^2 = 0.065, $p \leq 0.001$). The increase levels off after 200 hours but for the estimations to be comparable, same hour span (7 - 50) was used. I also chose only daytime positions from GPS data (between 05:00 – 22:00), since all VHF-data was collected during the day, and approximately 60 positions per individual were randomly chosen within this time-span.

2.5 Explanatory variables

The explanatory variables of individual fawns that were tested were age, number of ticks found during capture of fawn, proportion of agricultural area of fawn home range, sex, and mean birth weight. The included variables of individual adult females were home range size, mean weight, daily average movement, and age. The site-specific variables included were site, fox index, and mean temperature in June. Precipitation was dropped in all models due to low power because of rank deficiency when testing the most complex models. Final included variable was year of capture.

2.6 Date of birth

Date of birth (DOB) was estimated through a point system based on fawn behaviour possibly corresponding to a certain age and was developed from the original method Jullien et al. (1992). The original age estimation of Jullien et al. (1992) had a more thorough description of the umbilical cord than applied in this study. The categories

and point system in this study was instead primarily based on the behaviour of several fawns with known exact age, while umbilical cord state was checked and given points added accordingly (Table 1).

Table 1. *Point system for umbilical cord status*

State of umbilical cord	Points
Bloody/soft, red/white	0
Visible, brown	1
Visible, dry black	2
Visible, scar	3

An evaluation of certain types of behaviours was performed. These were: head position raised before capture (yes = 1, no = 0), ears moving before capture (yes = 1, no = 0), struggling during capture (yes = 1, no = 0), screaming during capture (yes = 1, no = 0), and lastly if the fawn ran away after release (yes = 1, no = 0). After summing up all points - a certain number of points corresponded to a certain age (Table 2).

Table 2. *The sum of a behavioural point system developed with inspiration by Jullien et al. (1992) indicate approximate age-span of fawn in days and also the right column shows the age in days used in the analysis*

Points	Approximate age (days)	Age used in analysis (days)
0	0	0
1	1 - 2	1.5
2	3	3
3	4 - 7	5.5
4	8 - 11	9.5
5	12 - 13	12.5
6	12 - 13	12.5
7	< 14	14

If all possible variables were monitored at capture, age was calculated directly from marking date. If not all variables were monitored, a minimum and a maximum was created, and a mean birth date estimated. Age was estimated for all captures and the determined date of birth (DOB) was the last possible date, meaning the youngest possible estimation of age. This since it was assumed that the capture event could have affected the behaviour of a fawn towards behaving older later on, but not the opposite. Then a correction for siblings was made by again choosing the latest possible date for all. The DOB was then checked for plausibility to avoid a date that would have been after first capture. Also, if the date was only one day before the first capture then the next possible date was used since this situation would have

been visible on the umbilical cord. If the umbilical cord was either red and bloody or soft and white, then the age was assumed to be zero regardless of behaviour.

The calculated DOB was used when extracting the included positions. I chose a time-interval between DOB and two months ahead. The choice to include the two months after birth was made due to that the predation risk of fox lasts to up until around six weeks (Aanes & Andersen, 1996) and the neonate hiding phase lasts for about one to two months (Linnell, 1994, in Linnell & Andersen, 1998). The risk of using a longer time-span would be to include fawns' movements outside the hiding period and therefore not within the youngest neonatal stage within two months from birth, in the aim of this thesis.

2.7 Other fawn variables

Tick estimates were based on counts of attached ticks found on each fawn at capture, and the tick variable was created by using the residuals from the regression between age in days and total number of counted ticks ($R^2 = 0.17$, $p \leq 0.0001$). This was done to correct for fawn age since an older age meant more attached ticks. Mean birth weight was calculated through an average of birth weights over multiple captures. Birth weight was calculated by multiplying age (DOB - Marking Date) with 0.15 kg to remove a mean weight gain for fawns per day (Linnell & Andersen, 1998; Jarnemo, 2004), then subtracting the weight gain from the weight at marking.

2.8 Site-specific variables

Fox index was an observation/effort index and calculated as a mean between 20 May and 20 June based on the number of fox observations divided by the number of people performing field work each day.

Roe deer index was based on spring pellet count surveys in both Grimsö and Bogesund and was made possible by the Swedish Infrastructure for Ecosystem Science (SITES), in this case by Grimsö Research Station, who conducted the surveys. Pellet counts were conducted every fall and spring through quadratic transects 1x1 km, and cleaned from pellets every fall to generate a more accurate winter density estimate. The number of sites depended on size of the area, in Grimsö 32 areas were surveyed with in total 600 sites (1 site/200 m) containing four circular plots/site. In total 2400 plots of 10 m^2 each (diameter 3.56 m). Pellet piles (1 pile $\geq$ 10 pellets) were counted in all plots. A mean number of pellet piles produced per 24 h of 22 was used which is recommended in pellet count surveys for roe deer (Cederlund & Liberg, 1995). The density index was calculated as follows and transformed into an estimate of number of individuals per km^2:

(Total no of piles in plots / Mean no of days since fall clean-up / Mean no of piles per roe deer per day) * Surveyed area (ha)

Summer temperature was included as the mean temperature in June each year to represent the impact of weather on fawn daily life and was collected from the open database SMHI Open Data (SMHI, 2016). The weather stations used were "Örebro" and "Kloten" for Grimsö, and "Skarpö" for Bogesund.

2.9 Variables of female roe deer

Female roe deer body mass, was based on weights retrieved during one or several repeated captures between 2.5 - 6.5 of age since weights are likely stable between these ages, which are considered as prime-age (Hewison & Gaillard, 2001). Using weights from repeated captures corrects for yearly variation and age effects on weight. If no weight had been taken within this interval of ages, then the closest corresponding older age's weight was used (7.5 or older). One weight of a young 1.5-year-old female (24.7 kg) was included since no other weight was available.

2.10 Statistical analyses

A linear mixed model (LMM) approach was used assuming a Gaussian distribution which was tested for by the Shapiro Test. The variable home range size (hereafter HR) was log-transformed to fit the distribution whereas DAM was already normally distributed. I tested ten different set of models for both home range size and daily average movement, based on two different datasets each.

First, for each main dependent variable, I created two global models based on the full dataset (HR n = 91, DAM n =118), and including the simple effects of Sex (two modalities), Site (two modalities: Bogesund vs. Grimsö), Age, proportion of agricultural area in fawn home-range (hereafter %Agr), Mean Birth Weight, Mean Tick Residuals (all numerical variables), Year, and as well as the two-way interaction between Site and %Agr. I excluded %Agr from the models explaining DAM because it the proportion of agricultural area was only possible to calculate from the fawns with a home range (n=91), and it would reduce the dataset to include this variable.

Secondly, to investigate in more detail the influence of site-specific variables, I performed another set of models including roe deer population index (hereafter Roe Index) and mean temperature in June instead of Site. That is, the most complex model tested in this second set of models included for HR: Roe Index, %Agr, Mean

Temperature, Year, Age, Mean Birth Weight, Mean Tick Res, and for DAM: Roe Index, Mean Temperature, Year, Age, Mean Birth Weight, Mean Tick Res, and Sex. The fox index variable (hereafter Fox) was not considered due to high correlation with Roe Index (0.89), and was instead investigated in separate analyses excluding the Roe Index (see Appendix 1). The variable Sex was excluded in HR to avoid overfitting the model (Hawkins, 2004).

Thirdly, to investigate the influence of mother characteristics on fawn performance, I conducted analyses with subsets of data from both response variables (HR n = 17, DAM n = 23) where the most complex model included for HR: Roe Index + Year + Age + Mother Home Range Size + Mother Age + Mother Mean Weight (hereafter Mother Body Mass) + Mean Birth Weight, for DAM: Roe Index + Year + Age + Mean Birth Weight + DAM Mother + Mother Age + Mother Body Mass. Site was not included in the subset analyses due only three fawns represented Bogesund in both dataset. Instead, Roe Index was included in one model and Fox in another (see Appendix 1) with all other variables similar as for the Roe Index. The variables Sex, %Agr, Mean Temperature, and Mean Tick Residuals were removed to avoid overfitting the smaller dataset and the variable collar type (VHF or GPS) was removed since there was no difference in DAM between the two ($t = 2.24$, $df = 2$, $p = 0.15$). The random effect mother ID was added in all the models to control for siblings. The included variables in the subsets were all chosen according to relevance and to avoid overfitting and to reduce the risk of downsizing the datasets because of missing values. For example, DAM mother was only included in the DAM models and the variable mother home range size was only included in the HR models.

The R^2-values used in the results are coefficients of determination calculated according to Nakagawa & Schielzeth (2013) and Johnson (2014). Models were compared and selected based on Akaike's Information Criterion (AIC) value (Burnham & Anderson, 2001) and according to the rule of parsimony, I selected the simplest model among models with a low difference in AIC value, having a $\Delta AIC < 2$ compared to the best model. I also present all the models with $\Delta AIC < 2$ because they have substantial support for being included in the discussion (Burnham et al., 1995).

Statistics were performed in the program R (R Core Team, 2015) and packages "adehabitatHR", "adehabitatLT", "rgdal", "MuMIn", "AICcmodavg" were used for home range and movement estimation, coordinate conversion, and for data analysis (Calenge, 2006; Bartoń, 2015; Bivand et al., 2016; Mazerolle, 2016).

3 Results

3.1 Descriptive results

In total, 47 male and 44 female fawns were included in the HR analysis and 63 males and 55 females were included in the DAM analysis. In the subset where mother-specific variables were included, the distribution was ten males and seven females. Gender distribution divided per site, showed that of the fawns of Grimsö, 26 were males and 27 were females in the HR analysis and 36 males and 35 females were in the DAM analysis. In Bogesund, there were 18 females and 20 males included in the HR analysis and 20 females and 27 males were included in the DAM. Mean birth date of all fawns was May 31st.

Mean home range size of all fawns was not significantly different in size from the mothers (Student's t-test, t = -0.35, df = 13.92, p = 0.73; Table 3). The same pattern was seen with the MCP-method (Table 3). Fawn home range size was larger in Grimsö than in Bogesund (Fig. 1).

Similarly, I found that females from Grimsö have larger home range sizes than those living in Bogesund, although the difference was not significant (N = 13, Student's t-test, t = 1.7689, df = 10.145, p = 0.107). When considering all available data on females, and not only females with radio-collared fawns, it did however result in significantly larger home ranges in Grimsö (mean = 136.1, median = 107.4) than at Bogesund (mean = 64.7, median = 63.5; N = 23, Student's t-test, t = 4.05, df

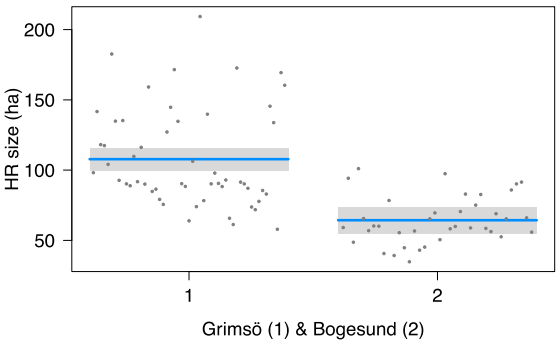

Figure 1. *Individual fawn home range sizes (y-axis) in Grimsö (1) and Bogesund (2) (x-axis) in Sweden, presented with confidence intervals (grey area) and means (blue lines).*

= 19.22, p = 0.0007). Daily average movements (DAM) was longer, but not significantly, in Grimsö compared to Bogesund for comparisons of both females and fawns (Table 3; Student's t-test, t < 1, p > 0.09, in both cases).

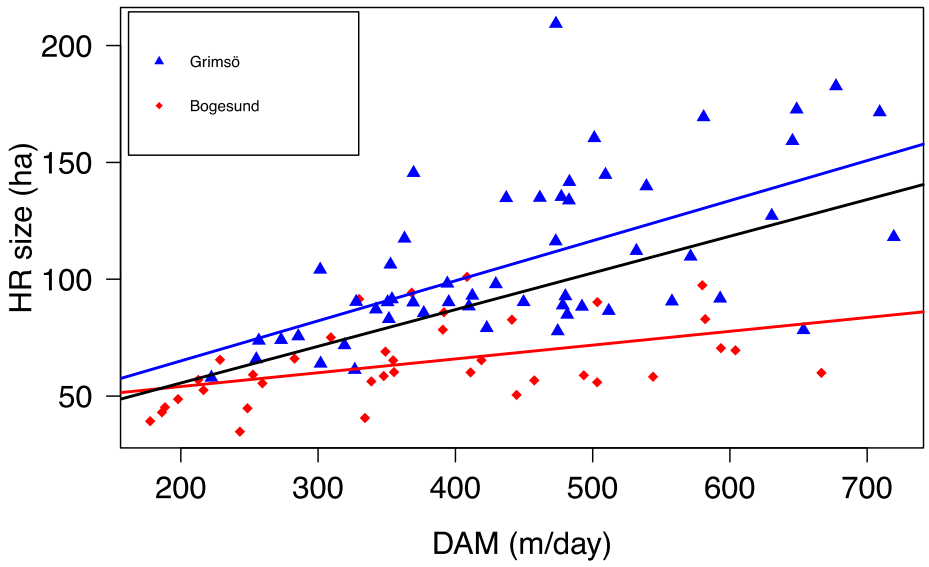

Figure 2. *Relationship between home range size and daily average movement of fawns (black line, R^2 = 0.36, p ≤ 0.0001), in Grimsö (blue triangles) and at Bogesund (red diamonds), based on VHF-collared neonate roe deer marked in southern Sweden 2013 – 2016.*

There was a significant positive relationship between DAM and fawn home range size (Fig. 2), both in Grimsö (R^2 = 0.39, p ≤ 0.0001) and Bogesund (R^2 = 0.23, p = 0.003). Mean per cent agricultural area of fawn home ranges was larger in Grimsö, but the median showed an opposite pattern, which meant that there were a few more extreme values (Table 3). There was no statistical difference in per cent agricultural land between sexes either (Student's t-test, t = -0.1999, df = 88.89, p = 0.84). There was no relationship between number of locations per fawn and generated size of home range, therefore no correction was made for this (R^2 = 0.009, p = 0.19).

Table 3. *Mean fawn and female home range size (ha), daily average movements (m/day), and proportion of agricultural area (%) estimated by two different methods (Kernel 90 and MCP). Sample size (N), median, and standard deviations (sd) are indicated for the two areas Bogesund (B) and Grimsö (G), all divided into three subgroups: Fawns, fawns with known mothers included in the subsets, and mothers. Fawns with known mother and mothers are included in the subset analyses and highlighted here in grey*

			Both areas		**Grimsö**		**Bogesund**	
	Type of measure	**N (G, B)**	**Mean (SD)**	**Median**	**Mean (SD)**	**Median**	**Mean (SD)**	**Median**
Fawn (all)	HR1 (K90)	91 (53, 38)	89.65 (35.98)	85.51	107.78 (35.12)	91.76	64.36 (16.97)	60.01
	HR2 (MCP)	91 (53, 38)	46.62 (30.28)	38.63	60.98 (31.09)	50.07	26.59 (11.81)	24.26
	% Agr (in HR1)	91 (53, 38)	13.3 (16.6)	6.6	14.2 (19.5)	5.7	12.1 (11.5)	8.4
	DAM (m/day)	118 (71, 47)	428.9 (140.7)	425.96	449.9 (144.8)	461.57	404.92 (133.2)	391.71
Fawn (subset)	HR1 (K90)	17 (14, 3)	109.16 (37.63)	92.74	118.24 (34.78)	102.23	66.79 (13.99)	58.87
	HR2 (MCP)	17 (14, 3)	63.6 (34.45)	48.29	70.99 (33.42)	59.89	29.13 (8.44)	24.35
	% Agr (in HR1)	17 (14, 3)	3.7 (5.6)	0	2.8 (4.1)	0	8.3 (5.5)	9.9
	DAM (m/day)	23 (20, 3)	492.22 (132.5)	493.59	494.88 (137.1)	494.76	474.48 (118.3)	493.59
Mother (subset)	HR1 (K90)	13 (10, 3)	94.72 (48.42)	83.14	102.06 (53.29)	94.3	70.26 (11.16)	64.29
	HR2 (MCP)	13 (10, 3)	59.67 (47.8)	49.91	66.9 (53.19)	53.11	35.59 (13.7)	31.41
	% Agr (in HR1)	13 (10, 3)	13.7 (6)	0	7 (4.4)	0	15.9 (9.4)	10.8
	DAM (m/day)	18 (15, 3)	353.13 (151.5)	291.03	366.33 (161.8)	299.13	287.1 (63.1)	282.93

The analysis including mothers for both HR and DAM included a wide age-span of females from 2 to 11 years old (mean age around 5 years old). Adult females were heavier in Grimsö than in Bogesund (Table 4, range between 21.7-30.1). Fox and roe deer density were clearly higher in Bogesund than Grimsö (Table 4). There were no differences between weight at birth between female and male fawns (Female mean = 1.89 kg, Male mean = 1.81 kg; DAM N = 118, Student's t-test, t = 0.74, df = 114.83, p = 0.46), but there was a difference in weights between sites (Grimsö mean = 1.89 kg, Bogesund mean = 1.71 kg; DAM N = 118, Student's t-test, t = 2.33, df = 110.58, p = 0.022).

Table 4. *Mean, standard deviation (SD), and sample size (N) of the variables Roe Index, Fox Index, Mother age, Mother Body Mass, Temperature, and Precipitation, with units in parentheses, are presented for both study areas as well as for Grimsö and Bogesund separately*

		Both areas		**Grimsö**		**Bogesund**	
Variable	**N**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Roe Index (ind/km^2)	7	2.74	2.65	0.9	0.36	5.18	2.27
Fox (ind/day)	7	0.13	0.1	0.08	0.02	0.2	0.13
Mother Age (HR, years)	13	4.62	2.43	4.8	2.74	4	1
Mother Age (DAM, years)	17	5.17	2.79	5.4	3	4	1
Mother Body Mass (HR, kg)	13	25.62	2.4	26.22	1.99	23.65	2.99
Mother Body Mass (DAM, kg)	17	25.48	2.45	25.87	2.25	23.65	2.99
Temperature (mean, June)	7	13.7	0.96	13.22	0.99	14.33	0.51
Precipitation (mm, June total)	7	54.89	25.94	56.85	31.83	52.27	21.92

3.2 Home range size

The best model selected included Site and Year only (Table 5A). The effects of both Bogesund and year 2016 were negative (Table 5B), in 2016, home ranges were considerably smaller (Fig. 6). Both variables had high importance along with % Agr (Table 5C), which was also included in the second-best model. With an increase in % Agr, the fawns showed a decrease in HR size.

Table 5A. *Model selection table on candidate models (Models) of the LMM analysis explaining home range size including the variable site together with number of parameters (K), log likelihood estimate (logLik), corrected Akaike's Information Criterion corrected for small sample sizes (AIC_c), Akaike's Information Criterion (ΔAIC), and weights of models (ω). Selected model highlighted in bold*

Models	**K**	**logLik**	**AIC_c**	**ΔAIC**	**ω**
Site + Year	**7**	**3.49**	**8.38**	**0.00**	**0.12**
% Agr + Site + Year	8	4.60	8.56	0.19	0.11
Sex + Site + Year	8	4.01	9.73	1.35	0.06
% Agr + Sex + Site + Year	9	5.17	9.88	1.50	0.06
% Agr + Site + Year + Site:% Agr	9	5.01	10.21	1.83	0.05

Table 5B. *Model-averaged estimates for each explanatory variable (Variable) including relative effects (Estimate), standard error (SE), adjusted standard error (Adjusted SE), z value (z), and p-value (p, significance highlighted in bold)*

Variable	Estimate	SE	Adjusted SE	z	*p*
(Intercept)	4.832	0.191	0.193	24.977	< 0.01
Site (B)	-0.522	0.072	0.073	7.176	**< 0.01**
Year 2014	-0.135	0.135	0.137	0.986	0.324
Year 2015	-0.157	0.133	0.135	1.159	0.246
Year 2016	-0.366	0.133	0.135	2.709	**0.007**
%Agr	-0.32	0.206	0.209	1.531	0.126
Sex (M)	0.038	0.035	0.036	1.048	0.295
Site (B):%Agr	0.397	0.448	0.455	0.873	0.383
Age	0.001	0.005	0.005	0.269	0.788
Mean Tick Res	0.0005	0.008	0.008	0.062	0.951
Mean Birth Kg	-0.002	0.044	0.044	0.048	0.962

Table 5C. *The relative importance (Importance) of each variable and the number of models the variable is included in (N models = 160, N individuals = 91)*

Variable	Site	Year	% Agr	Sex	Age	Mean Tick Res	Mean Birth Kg	% Agr:Site
Importance	1.00	0.93	0.56	0.34	0.23	0.23	0.22	0.17
No of models	96	80	96	80	80	80	80	32

For the site-specific model, Roe Index was the only variable retained in the best model (Table 6A), with lower densities resulting in larger home ranges (Table 6B, Fig. 5). Considering model-averaging the most important variables were Roe Index and % Agr, but Mean Temp is also worth mentioning (Table 6C). Both the % Agr and Mean Temp had negative, but not significant effects on HR size.

Table 6A. *Model selection table on candidate models (Models) of the LMM analysis explaining home range size including the site-specific variables Roe Index and Mean Temp together with number of parameters (K), log likelihood estimate (logLik), corrected Akaike's Information Criterion corrected for small sample sizes (AIC_c), Akaike's Information Criterion (ΔAIC), and weights of models (ω). Selected model highlighted in bold*

Models	K	logLik	AIC_c	ΔAIC	ω
Roe Index	**4**	**1.44**	**5.59**	**0.00**	**0.09**
% Agr + Roe Index	5	2.55	5.61	0.02	0.09
Mean Temp + Roe Index	5	2.01	6.68	1.09	0.05
Mean Tick Res + Roe Index	5	1.93	6.84	1.25	0.05
% Agr + Mean Temp + Roe Index	6	3.08	6.84	1.25	0.05
% Agr + Mean Birth Kg + Roe Index	6	2.80	7.40	1.80	0.04
% Agr + Mean Tick Res + Roe Index	6	2.78	7.43	1.84	0.04
Mean Birth Kg + Roe Index	5	1.62	7.46	1.87	0.04
Age + Roe Index	5	1.60	7.50	1.90	0.04
% Agr + Age + Roe Index	6	2.71	7.58	1.99	0.03

Table 6B. *Model-averaged estimates for each explanatory variable (Variable) including relative effects (Estimate), standard error (SE), adjusted standard error (Adjusted SE), z value (z), and p-value (p, significance highlighted in bold)*

Variable	Estimate	SE	Adjusted SE	z	*p*
(Intercept)	5.095	0.757	0.761	6.693	< 0.01
Roe Index	-0.011	0.002	0.002	5.820	**< 0.01**
%Agr	-0.288	0.196	0.199	1.449	0.147
Mean Temp	-0.067	0.062	0.062	1.075	0.283
Mean Tick Res	-0.006	0.009	0.008	0.705	0.481
Mean Birth Kg	0.025	0.044	0.044	0.555	0.579
Age	0.003	0.005	0.005	0.560	0.575
Year 2014	-0.293	0.143	0.145	2.028	**0.043**
Year 2015	-0.298	0.163	0.165	1.809	0.071
Year 2016	-0.261	0.136	0.138	1.897	0.058

Table 6C. *The relative importance (Importance) of each variable and the number of models the variable is included in (N models = 128, N individuals= 91)*

Variable	Roe Index	% Agr	Mean Temp	Mean Tick Res	Mean Birth Kg	Age	Year
Importance	1.00	0.47	0.39	0.29	0.27	0.26	0.22
No of models	64	64	64	64	64	64	64

Since the Roe Index and Fox were heavily correlated it was not possible to include them both in the same models. To find out if the density of predators influenced the home range size of fawns, I conducted a separate analysis without Roe Index and instead including Fox (see Appendix 1, Table 1A). In this analysis, the most parsimonious model was instead including the variables Fox, Mean Temp, and Year, of which all were significant, had negative effects, and had high importance values >0.98 (see Appendix 1, Table 1A-C). The variable, % Agr, also had relatively high importance and low p-value, showing the tendency of a prevalent effect.

When investigating the influence of mother characteristics, the best model was including Mother Body Mass and Roe Index (Table 7A). Both Mother HR Size and Mother Body Mass were included in the top models and had similar weights (respectively differing by 0.02 and 0.04 from the best model). Fawn HR size increased with increasing adult Mother HR Size (Fig. 3; Table 7B), even though an outlier strongly affected that relationship rendering it not significant when tested separately. When considering the principle of parsimony, the subset showed again that Roe Index was the strongest determinant of the size. The chosen model for fawn HR size was therefore only including Roe Index. Most important variables were Roe Index and Mother HR Size (Table 7C).

Table 7A. *Model selection table on candidate models (Models) of the LMM analysis explaining home range size including the mother quality variables and Roe Index together with number of parameters (K), log likelihood estimate (logLik), corrected Akaike's Information Criterion corrected for small sample sizes (AIC_c), Akaike's Information Criterion (ΔAIC), and weights of models (ω). Selected model highlighted in bold*

Models	K	logLik	AIC_c	ΔAIC	ω
Mother Body Mass + Roe Index	5	4.60	6.26	0.00	0.17
Mother HR Size + Roe Index	5	4.46	6.53	0.28	0.15
Roe Index	**4**	**2.21**	**6.90**	**0.65**	**0.13**
Mother HR Size	4	2.04	7.25	0.99	0.11

Table 7B. *Model-averaged estimates for each explanatory variable (Variable) including relative effects (Estimate), standard error (SE), adjusted standard error (Adjusted SE), z value (z), and p-value (p, significance highlighted in bold)*

Variable	Estimate	SE	Adjusted SE	z	*p*
(Intercept)	5.683	1.833	1.894	3.000	0.0027
Mother Body Mass	-0.064	0.04	0.043	1.484	0.138
Roe Index	-0.017	0.007	0.008	2.298	**0.022**
Mother HR Size	0.004	0.002	0.002	1.896	0.058
Age	-0.048	0.045	0.048	0.994	0.32
Mother Age	0.003	0.036	0.039	0.078	0.938
Mean Birth Kg	0.048	0.098	0.107	0.443	0.658
Year 2014	0.024	0.297	0.312	0.076	0.939
Year 2015	0.451	0.349	0.364	1.240	0.215
Year 2016	-0.069	0.33	0.348	0.197	0.844

Table 7C. *The relative importance (Importance) of each variable and the number of models the variable is included in (N Models = 128, N Individuals = 17)*

Variable	Roe Index	Mother HR Size	Mother Body Mass	Age	Mean Birth Kg	Mother Age	Year
Importance	0.71	0.42	0.31	0.17	0.10	0.10	0.02
No of models	64	64	64	64	64	64	64

In this subset analysis, the variable Site was excluded due to low sample size. Mother Body Mass was here included in one of the top models and was the third most important variable (Table 7C). Mother Body Mass was also significantly lower

at Bogesund than in Grimsö which contributed to this result (Student's t-test, t = 5.0671, df = 21.666, p ≤ 0.0001).

Similar as with the full dataset, I conducted a separate analysis including Fox instead of Roe Index (see Appendix 1, Table 2A). In these candidate models, the variable Mother HR Size was significant and was the only one included in the most parsimonious model. It had a considerably higher weight than the other models and a ΔAIC < 2. Fox had an importance of 0.38 and was the only variable in second simplest model (see Appendix 1, Table 2C). Fox had similar negative effect on HR size as in the full dataset (see Appendix 1, Table 2B). The positive relationship between Mother and fawn HR size was tested separately as well through log-transformed linear regression excluding top right outlier in graph (n =16, R^2 = 0.016, p = 0.28, Fig. 3).

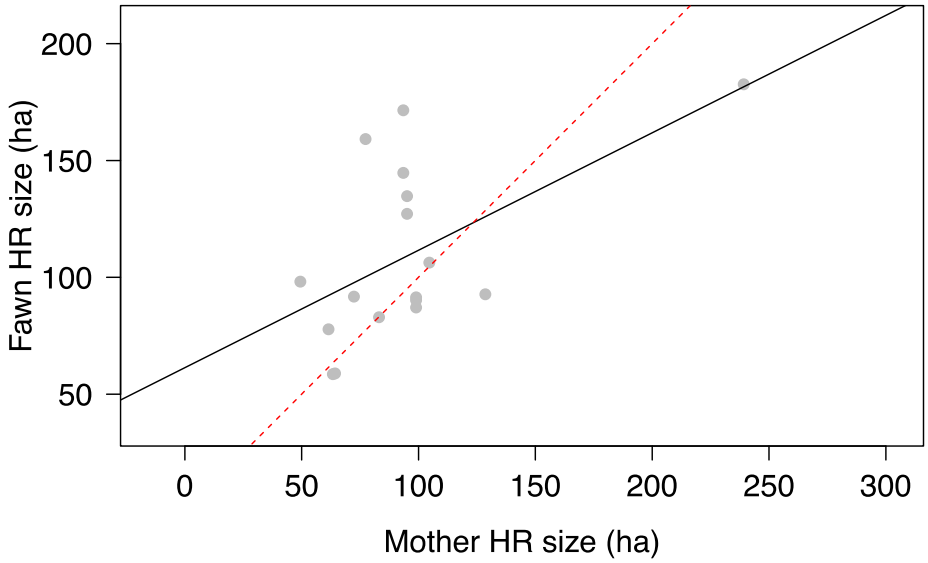

Figure 3. *The relationship (black line) between roe deer mother and neonate home range sizes generated from locations collected in southern Sweden 2013 – 2016 compared to the expected 1:1 relationship between the two (dashed red line).*

3.3 Daily average movement

The first DAM dataset analysed showed that the most parsimonious model included the variables Site and Year, the same result as for the home range size (Table 8A). Fawns in Bogesund had a significantly lower DAM than in Grimsö (with 85 m less

movements per day, i.e. 19 % of the DAM mean in Grimsö; Table 3; Table 8B). The effect of DAM was also 114 m shorter per day for the year 2016 compared to other years. I obtained similar results when considering the relative importance from model-averaging, as the most important variables were Year and Site (Table 8C, Fig. 4A; Fig 4B). The positive effect of Mean Tick Res had a relatively high importance as well and was included in two of the five top models ΔAIC <2.

Table 8A. *Model selection table on candidate models (Models) of the LMM analysis explaining daily average movement including the site variable together with number of parameters (K), log likelihood estimate (logLik), corrected Akaike's Information Criterion corrected for small sample sizes (AIC_c), Akaike's Information Criterion (ΔAIC), and weights of models (ω). Selected model highlighted in bold*

Models	K	logLik	AIC_c	ΔAIC	ω
Site + Year	**7**	**-731.60**	**1478.21**	**0.00**	**0.18**
Mean Tick Res + Site + Year	8	-730.61	1478.55	0.34	0.15
Mean Birth Kg + Mean Tick Res + Site + Year	9	-729.85	1479.36	1.15	0.10
Mean Birth Kg + Site + Year	8	-731.31	1479.94	1.73	0.08
Sex + Site + Year	8	-731.38	1480.08	1.87	0.07

Table 8B. *Model-averaged estimates for each explanatory variable (Variable) including relative effects (Estimate), standard error (SE), adjusted standard error (Adjusted SE), z value (z), and p-value (p, significance highlighted in bold)*

Variable	Estimate	SE	Adjusted SE	z	*p*
(Intercept)	508.926	54.71	55.208	9.218	<
Site (B)	-84.744	27.106	27.404	3.092	**0.002**
Year 2014	33.095	45.933	46.416	0.713	0.476
Year 2015	-68.974	44.156	44.62	1.546	0.122
Year 2016	-113.768	43.263	43.726	2.602	**0.009**
Mean Tick Res	5.268	3.368	3.404	1.547	0.122
Mean Birth Kg	19.3	19.024	19.224	1.004	0.315
Sex (M)	-15.791	22.106	22.353	0.706	0.48
Age	-0.363	0.977	0.987	0.367	0.713

Table 8C. *The relative importance (Importance) of each variable and the number of models the variable is included in (N models = 64, N individuals = 118)*

Variable	Year	Site	Mean Tick Res	Mean Birth Kg	Sex	Age
Importance	0.99	0.97	0.51	0.35	0.29	0.25
No of models	32	32	32	32	32	32

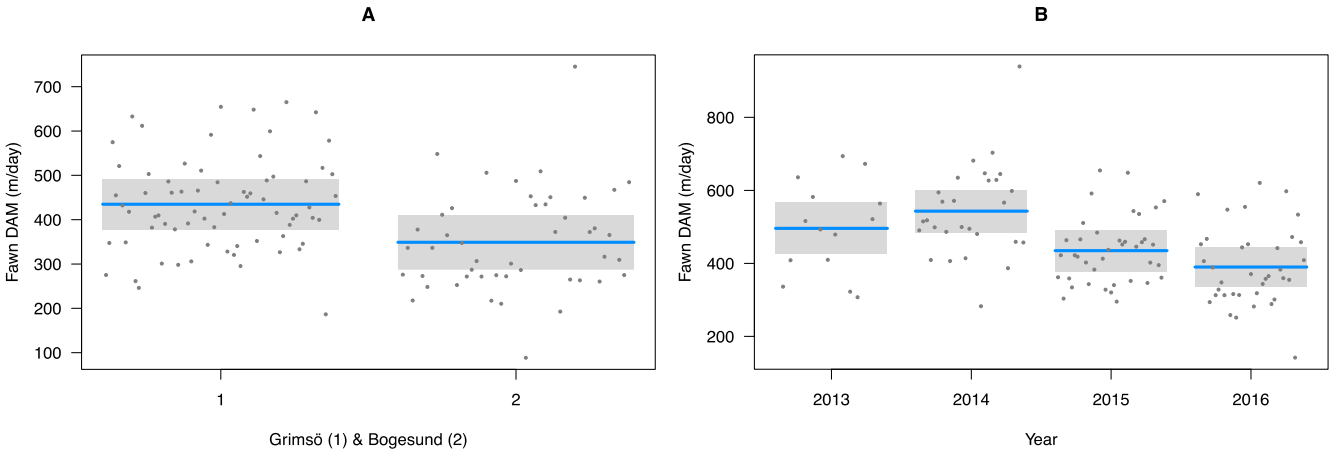

Figure 4. *The predicted relationship (blue line) with confidence interval (grey area) of the model output from Table 8A-C displaying individual daily movements of neonates with* ***A)*** *site, and* ***B)*** *year, both generated from locations collected in southern Sweden 2013 – 2016.*

The same dataset with the site-specific model showed that Roe Index and Year were the two variables included in the most parsimonious model (Table 9A). The two variables were both significant and caused negative effects on DAM (Table 9B). DAM was only reduced by 2 m with increasing density of roe deer (range between 0.57 – 7.81 ind/km^2). Important variables were the same as the ones selected in the most parsimonious model (Table 9C). The variable Mean Tick Res did again have high importance with its positive effect.

Table 9A. *Model selection table on candidate models (Models) of the LMM analysis explaining daily average movement including the site-specific variables Roe Index and Mean Temp together with number of parameters (K), log likelihood estimate (logLik), corrected Akaike's Information Criterion corrected for small sample sizes (AIC_c), Akaike's Information Criterion (ΔAIC), and weights of models (ω). Selected model highlighted in bold*

Models	K	logLik	AIC_c	ΔAIC	ω
Roe Index + Year	**7**	**-731.08**	**1477.17**	**0.00**	**0.12**
Mean Tick Res + Roe Index + Year	8	-730.40	1478.13	0.96	0.07
Mean Birth Kg + Roe Index + Year	8	-730.60	1478.52	1.34	0.06
Mean Birth Kg + Mean Tick Res + Roe Index + Year	9	-729.45	1478.56	1.38	0.06
Roe Index + Sex + Year	8	-730.90	1479.13	1.95	0.04

Table 9B. *Model-averaged estimates for each explanatory variable (Variable) including relative effects (Estimate), standard error (SE), adjusted standard error (Adjusted SE), z value (z), and p-value (p, significance highlighted in bold)*

Variable	Estimate	SE	Adjusted SE	z	*p*
(Intercept)	636.45	298.765	300.284	2.119	0.034
Roe Index	-1.854	0.685	0.691	2.681	**0.007**
Year 2014	7.582	46.777	47.236	0.161	0.872
Year 2015	-89.085	53.237	53.684	1.659	0.097
Year 2016	-99.191	44.685	45.159	2.197	**0.028**
Mean Tick Res	4.952	3.4034	3.44	1.440	0.15
Mean Birth Kg	20.274	19.023	19.22	1.055	0.292
Sex (M)	-13.656	22.28	22.525	0.606	0.544
Mean Temp	-25.392	30.567	30.786	0.825	0.409
Age	-0.396	0.975	0.986	0.402	0.688

Table 9C. *The relative importance (Importance) of each variable and the number of models the variable is included in (N models = 128, N individuals = 118)*

Variable	Roe Index	Year	Mean Tick Res	Mean Birth Kg	Mean Temp	Sex	Age
Importance	0.88	0.87	0.47	0.36	0.34	0.27	0.25
No of models	64	64	64	64	64	64	64

A second analysis path trying to explain the variation in DAM was performed including Fox while Roe Index was excluded. The best model was the same as for

the home range size with Fox, Mean Temp, and Year, with all having negative effects on DAM (see Appendix 1, Table 3A-B). The most parsimonious model however included only Fox and Year. Year was a significant variable while Fox was on verge of significance (see Appendix 1, Table 3B, p = 0.055). The relative importance of Fox was more important than the Roe Index. All the variables Fox, Mean Temp, Year, Mean Tick Res, and Mean Birth Kg had high to relatively high importance, but the importance of Year was lower in the analysis including Fox than in the Roe Index analysis path (Table 9C; see Appendix 1, Table 3C). Importance of Mean Temp was double compared to the site-specific model with the Roe Index instead (see Appendix 1, Table 3C).

Finally, analysis of DAM with the subset of data on fawn-mother pairs, showed that none of the included variables were in the most parsimonious model (Table 10A). Therefore, the null model was selected, whereas the model including Mother Age was in second place. None of the variables showed significant effects (Table 10B). The importance of both Mother Age and fawn Age in relation to the sum of weights ΔAIC < 2 showed that they both might have had some effect in explaining the variation (Table 10C).

Table 10A. *Model selection table on candidate models (Models) of the LMM analysis explaining daily average movement including the mother quality variables and Roe Index together with number of parameters (K), log likelihood estimate (logLik), corrected Akaike's Information Criterion corrected for small sample sizes (AIC_c), Akaike's Information Criterion (ΔAIC), and weights of models (ω). Selected model highlighted in bold*

Models	K	logLik	AIC_c	ΔAIC	ω
(Null)	**3**	**-143.20**	**293.67**	**0.00**	**0.19**
Mother Age	4	-142.11	294.45	0.78	0.13
Age	4	-142.55	295.32	1.64	0.08

Table 10B. *Model-averaged estimates for each explanatory variable (Variable) including relative effects (Estimate), standard error (SE), adjusted standard error (Adjusted SE), z value (z), and p-value (p, significance highlighted in bold)*

Variable	Estimate	SE	Adjusted SE	z	*p*
(Intercept)	457.895	236.646	247.826	1.848	0.065
Mother Age	-16.609	11.18	11.978	1.387	0.166
Age	4.835	3.305	3.542	1.365	0.172
DAM Mother	-0.161	0.225	0.24	0.673	0.501
Roe Index	-1.433	2.796	2.993	0.479	0.632
Mean Birth Kg	-7.83	51.473	55.124	0.142	0.887
Mother Body Mass	1.258	12.929	13.834	0.091	0.928
Year 2014	-39.907	88.186	94.311	0.423	0.672
Year 2015	-81.036	82.794	89.234	0.908	0.364
Year 2016	-139.297	81.867	88.348	1.577	0.115

Table 10C. *The relative importance (Importance) of each variable and the number of models the variable is included in (N models = 128, N individuals = 23)*

Variable	Mother Age	Age	DAM Mother	Roe Index	Mother Body Mass	Mean Birth Kg	Year
Importance	0.35	0.27	0.21	0.18	0.16	0.16	0.01
No of models	64	64	64	64	64	64	64

The analysis was performed exchanging Fox for Roe Index and resulted in the same outcome by not rejecting the null model (see Appendix 1, Table 4A-C). However, this analysis with Fox resulted in a larger effect by a decrease of 46 m compared to Roe Index with < 2 m decrease.

3.4 Summary of results

Based on all eight different models (with four datasets), the most parsimonious models selected are presented (Table 11) and showed that Site, Year, and Roe Index are the most common features included (Fig. 1; Fig. 4A; Fig. 4B; Fig. 5; Fig. 6).

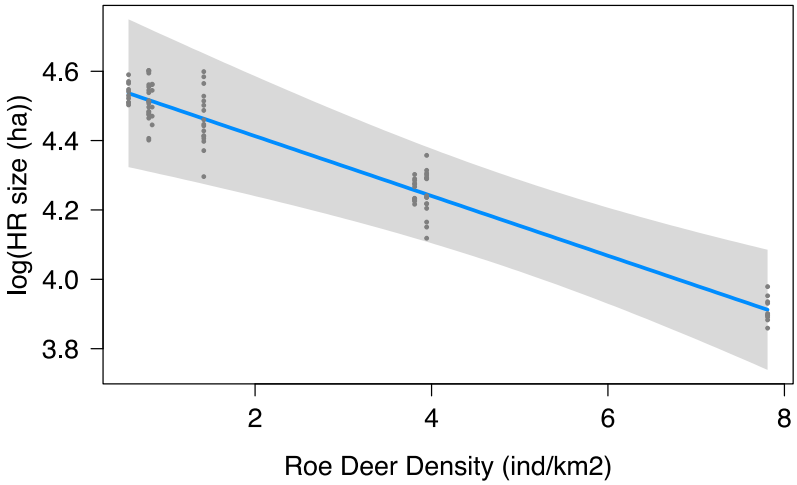

Figure 5. *The predicted relationship (blue line) with confidence interval (grey area) from the model output from Table 6A-C of individual variation of fawns' home range sizes (y-axis), generated from locations collected in two areas in Sweden (Grimsö & Bogesund) 2013 – 2016, over a range of roe deer densities (x-axis).*

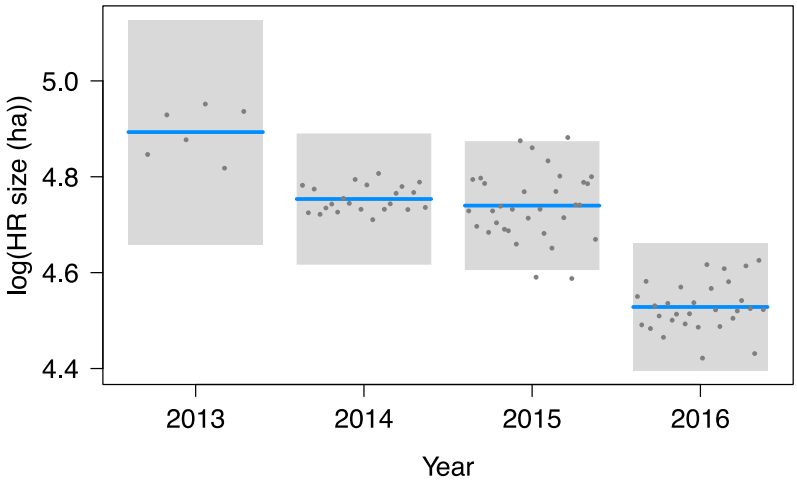

Figure 6. *The predicted relationship from the model output from Table 5A-C of variation of neonate roe deer home range sizes (y-axis) between years (x-axis) generated from locations collected in two areas in Sweden (Grimsö & Bogesund) 2013 – 2016. Individual home range sizes (points), means (blue lines), and confidence intervals (grey areas) are displayed.*

In the site-specific model for both HR and DAM the final variables included were Site and Year, whereas the site-specific models for HR included only Roe Index, while DAM included both Roe Index and Year. The subset of HR displayed the same parsimonious model as for the full dataset with Roe Index being the only variable included. By comparing models with or without the mother identity included as a random factor, individual variation among mothers appeared to account for a large part of the variance in fawn HR sizes, as suggested by the marked increase observed in the R^2-values (Table 11). There was also some variation between individuals for DAM, but not as much as for HR size. The variable Year was often included in the selected best models and there was a clear pattern of smaller home ranges during 2016 and larger in 2013 (Fig. 6).

Table 11. *The selected, most parsimonious models (Model) and their correlation coefficients from different analyses (Origins displayed by referral to table or appendix table) of fixed effects (Marginal R^2) and both fixed and random effects (Conditional R^2). Response variables home range size (HR) and daily average movement (DAM) are both represented excluding subsets of daily average movements for the roe deer index and fox index where the null model was accepted for both*

Model	**Table**	**Marginal R^2**	**Conditional R^2**
log(HRsize) ~ Site + Year + (1| MotherID)	5A	0.515	0.926
log(HRsize) ~ Roe Index + (1| MotherID)	6A	0.483	0.925
log(HRsize) ~ Fox + Mean Temp + Year + (1| MotherID)	Ap. 1:1A	0.53	0.928
log(HRsize) ~ Roe Index + (1|MotherID)	7A	0.322	0.962
log(HRsize) ~ Mother HR size + (1|MotherID)	Ap. 1:2A	0.295	0.962
DAM ~ Site + Year + (1| MotherID)	8A	0.263	0.314
DAM ~ Roe Index + Year + (1| MotherID)	9A	0.269	0.322
DAM ~ Fox + Year + (1| MotherID)	Ap. 1:3A	0.236	0.318

4 Discussion

This study showed that neonate roe deer home range size was influenced by site, roe deer population density, fox density, temperature, mother home range size, and year, which were all included in the selected best models and had varying importance. Prediction (1) stated that fawn home range size and daily movements are larger and longer in Grimsö than in Bogesund and was confirmed. The home range sizes of fawns are also positively related to their mothers' home range size, thereby partly accepting prediction (2) as well. However, the movement of fawns was seemingly not explained by any of the other mother characteristics such as mother body mass, age, or movement. High densities of roe deer and fox were, as expected in prediction (3), negatively affecting home range size and movements. The proportion of agricultural land did not cause any effect on home range size or movements, thereby rejecting the part of prediction (3) saying that increasing amounts of agricultural land would result in fawns moving less and over smaller areas. Prediction (4) stating that fawn home range size and movements would vary with environmental influence and year was in part both accepted and rejected. Both home range size and movements varied between years as expected, but temperatures showed to have the opposite than expected effect as increasing temperature led to smaller home ranges. Since precipitation was never tested I could neither accept or reject this prediction. Considering the intrinsic effects of sex, age, and birth weight of the fawns, none of the factors caused effects on either individual size of home range or movement. There are no differences in early somatic growth rates between genders (Andersen & Linnell, 1997), justifying combing sexes in some of the analyses on the neonates, in this study. The age of the youngest fawn with a home range was 37 days, which correspond to > 5 weeks of age and close to the age where predation risk decreases rapidly (Aanes & Andersen, 1996; Jarnemo et al., 2004), which in turn may be a reason for the lack of effect by age. Finally, tick burden on neonates did not explain any significant variation in HR or DAM, although it was of some importance in the latter. Therefore, both predictions 5 and 6 were rejected.

Further, neonate roe deer daily movements and home range sizes were significantly and positively related, meaning that there is possibly a causal relationship between the two. This means that animals with large home ranges also move over longer daily distances. Whether movements are frequent and short, or few and long, is not analysed here and is instead a topic for the future. These findings are of use when discussing the different effects in further detail.

4.1 Differences between sites

As mentioned, fawn home range size was larger in Grimsö than Bogesund. That home range size of adults is habitat-dependent have been shown by previous studies (Börger et al., 2006), and here, it seems that a similar relationship exists in neonate roe deer home range size as well, although between sites instead of specific habitats. Roe deer have a plastic behaviour when it comes to foraging and anti-predator traits which can increase their survival (Abbas et al., 2011; Bonnot et al., 2015), and argues for that they may easily adjust to local characteristics. The difference between sites shows that local effects can influence home range sizes and daily average movements of fawns. There can be multiple reasons for fawn home ranges being larger in Grimsö and some are highlighted below.

4.1.1 Index of roe deer density and the proportion of agricultural land

In Bogesund, the density of roe deer is high compared to Grimsö and the high roe deer index did also correlate with a decrease in home range size (Table 4; Table 6A-B). The differences in densities are especially clear when visually examined (Fig. 5). The relationship between home range size and roe deer density also agrees with what Kjellander et al. (2004) found for adult roe deer in the same area (Bogesund). Although the proportion of agricultural area was not found to influence home range size (Table 5B; Table 6B; see Appendix 1, Table 1B), it may indirectly affect roe deer density by increasing carrying capacity of a habitat (Drożdż, 1979). Considering the high total proportion of agricultural land (i.e. a broad proxy for food availability) in Bogesund this may result in a smaller home range size due to the overall increased and compressed food availability, allowing a more energy-efficient food search.

However, since the food availability (i.e. proportion of agricultural area) for the mother did not affect fawn home range size, what could else could cause roe deer density to affect fawn home range size negatively? Female roe deer are not territorial as the males are during the rut (Vanpé, 2007) but they do avoid each other during summer months by showing less overlap during the fawning season (Maublanc et

al., 2012). Female roe deer also show more aggression towards each other during the fawning season with half of all aggressive encounters being performed in the first ten days after birth (Maublanc et al., 2012). This avoidance behaviour can therefore lead to smaller home ranges in high density areas. However, another measure of food availability may have been better suited in this study since there is no overall index for food availability including all habitats. A total measure of food availability could be an important determinant of fawn home range size since it has been shown to be a good predictor for adult female home ranges (Saïd et al., 2009; Morellet et al., 2013).

If home range size is largely due to roe deer density, high densities can force individuals to inhabit a more sub-optimal forested area, which relates to higher predation risk due to the predictability and a decrease of hiding places for fawns (Panzacchi et al., 2009; Van Moorter et al., 2009). The high density will also result in an increasing importance of habitat quality, with low quality causing increased fawn mortality (Pettorelli et al., 2003). Consequently, this fragile relationship will be even more susceptible to environmental fluctuations and human-caused changes. Therefore, I believe that a female and its fawn will have less possibility to exploit new areas if the original home range is disturbed by for example mowing, which will cause a shift in the preferred habitat (Linnell et al., 2004). Forage in the "new" home range will then sustain more inhabitants. Mowing could potentially have influenced fawn home range size in this relation. Mowing affects the fawn's preference of a farmland habitat for cover and the mother´s for food (Linnell et al., 2004). Since habitat choice in an agricultural landscape has been shown to be more based on the vegetation development rather than the age of fawns (Linnell et al., 2004), it would have been advantageous to have known the time when mowing occurs. Other consequences due to high roe deer density may be apparent in the following year due to a decreased adult body mass of fawns born in a high-density area and consequently an increase in stillbirths (Andersen & Linnell, 1998; Pettorelli et al., 2002).

The high roe deer density also caused small but decreasing effects on daily movements. The effect of movements was greater in Bogesund. Perhaps the potential avoidance pattern between individuals that appears at high roe deer densities slightly decreases movement. Though not likely a major decrease since the mother will have the same energetic requirements and should aim for moving in relation to necessary food intake. However, decreasing possibilities to move may be one of the limitations causing low adult body mass of fawns born in high density areas (Toïgo et al., 2006) and lower birth weights when born during a peak (Gaillard et al., 1997). This means that the density of roe deer might have amplifying and long-lasting effects on fawns through the decrease in both home range size and movements on body mass and ultimate fitness.

4.1.2 Index of fox density

The fox density was higher in Bogesund and was also a factor shown to affect home range size and movements of roe deer fawns as well (see Appendix 1, Table 1A-C; see Appendix 1, Table 3A-C), similar to what was expected. The corresponding pattern has been found in voles as well where the presence of predators decreased home range size significantly, and was interpreted as a direct behavioural adjustment to avoid contact with predators (Desy et al., 1990). Roe deer fawns in areas with low fox density could therefore advantageously have a larger home range without an increasing risk.

In addition to the high fox density, the total coverage of agricultural areas in Bogesund can influence the behaviour of fawns. Since it is more difficult to find hidden fawns in an agricultural area, the predation risk might decrease with less movement (Panzacchi et al., 2009) and subsequently, having a smaller home range since these factors are correlated (Fig. 2). Fawns moving less therefore survive, while fawns moving more suffer from higher rates of predation, causing the negative effect on fawn movements and home range size.

However, it would have been interesting to investigate other predators as well, even though the fox index is lower in Grimsö, the roe deer in this area have in total more predators to avoid, e.g. fox, lynx, and wolf, although predation by wolves still seems to be of lesser importance (Davis et al., 2016). After all, mortality caused by lynx can represent a large proportion of total fawn mortality (Jędrzejewski et al., 1993; Nordström, 2010).

4.1.3 Year

The yearly variation seen on both daily movements and home range size of fawns in this study is explained to some extent by the variation in roe deer and fox densities. Year also corresponds to some stochastic variability that has not been included in the model. For example, the vole populations of two study areas, Grimsö and Bogesund, are factors affecting food availability for foxes, and a decrease in the voles will lead to an increasing offtake of roe deer fawns (Kjellander & Nordström, 2003). With the foxes focusing more on roe deer in the poor vole years, this can potentially cause effects on both female and fawn behaviour and their daily movements. Consequently, also an indirect effect on the home range size of fawns, due to the correlation shown in this study (Fig. 2). In fact, a vole index (methodology see Kjellander & Nordström, 2003) estimated in both Grimsö and Bogesund, reveal that the vole population size was low from spring 2015 to spring 2016 in Grimsö and a low vole density in Bogesund in spring 2016 as well. In any case, the fall vole index shows a strong increase in Grimsö 2016 that potentially could have the above-

described impact. Especially for 2016 when a smaller home range size was observed in this study (Fig. 6). A question that follows is if the Grimsö fall increase in voles leads to an increase in home range size in 2017's fawns? This remains to be seen.

Further explanations for the effect on home range size in 2016 were that this year coincided with peak fox and roe deer densities in Bogesund which might cause the decreasing home ranges. However, both densities were just slightly under the mean for Grimsö.

4.1.4 Environmental factors

The difference between sites could also be attributed to environmental factors. In a study within northern Europe, home range size of roe deer decreased with increasing temperature and NDVI (Normalized Difference Vegetation Index, Morellet et al., 2013). The temperature was higher in Bogesund than Grimsö in this study (Table 4). Mean temperature was consistently negatively affecting both home range size and daily movements in my study which was opposite to my expectations. A previous study found that younger fawns avoiding light penetration increased their survival (Van Moorter et al., 2009). Therefore, the result observed in this study may have shown decreasing movements due to avoidance of hyperthermia.

There can be an indirect effect of temperature in this study as well since higher temperature may lead to increase growth of vegetation, although the effect of temperature does vary (Rustad et al., 2001). Thus, the need to move decreases and home ranges of adult females can be smaller to reduce energy expenditure while foraging (Saïd et al., 2009; Morellet et al., 2013).

Roe deer density, fox density, temperature, and total proportion of agricultural land in Bogesund may all together explain some of the variation in neonate roe deer home range size, although the three first factors are the only ones significantly shown to do so in this study. However, the results revealed that there was a lot of individual variation in home range size, suggesting that more factors are explaining the resulting size.

4.2 Mother characteristics

Finally, my expectations that mother's characteristics influence fawn home range size and movements are partially supported. Especially for variations in home range size which are markedly accounted for by individual variation between mothers. Indeed, although around 50% of the variance in home range size is explained by the correlation with environmental factors (site, year, roe deer density, fox density, and

mean temperature) more than 90% of the variance is explained when also accounted for by mother identities. Concerning the mother's characteristics tested, the size of a female's home range did show a positive relationship with its fawn's home range, which means that the fawn inherits a wider movement pattern from its mother. The relatively small sample size in this study does, however, warrant caution about the results. Though, an argument reinforcing this result could be that for example fawn body mass (Andersen et al., 2000) is correlated with mothers' characteristics showing an inheritance. Further, the success rate in defending its young (Jarnemo, 2004) should result in a limited maximal distance between fawns and females. Home range size is also dependent on food availability (Panzacchi et al., 2010), which would explain why the mothers do not simply decrease their home range size to stay close to their young. Further arguing for the connection is that predation risk is only considered secondarily after food availability (Panzacchi et al., 2010). Therefore, a plausible explanation is that the fawn must move with the mother for the latter to find forage. The simultaneous movement pattern between females and fawns is more pronounced in a forested habitat and they also have the shortest distance between each other when they are active (Panzacchi et al., 2010). This fact, in combination with the relatively high percentage of forested habitats in both areas, can explain the relationship between the two. The connection would also explain why there were similar effects on home range size for both fawns and females by, for example, high roe deer density (Kjellander et al., 2004).

4.3 Improvements

There was an unexpected difference between fawn and female home range size in this study. One might assume that the fawn will have a smaller home range size than its mother since it will only move to where the female has left the fawn (Van Moorter et al., 2009), at least within a short distance (pers. comm. A. Jarnemo, 15 January 2017). In this study, the mean home range size of fawns in Grimsö was equivalent, or even slightly larger than their mother during the same time. It may be explained by the presence of certain predators which in the white-tailed deer results in the fawn moving over larger distances and sometimes out of the mother's territory (Ozoga & Verme, 1986). It could also be due to the differences in radio-tracking equipment. The adult females included in the HR analysis wore a GPS-collar, while all the fawns have been wearing VHF-collars. There was no difference in daily average movement between VHF- and GPS-collars of females (Student's t-test, $t = -0.53$, $df = 3.44$, $p = 0.63$), but this does not prove that there may be errors in the fawns' positions. From experience, the mothers' VHF-collars are easier to find and track, probably due to them being higher up and carry a stronger transmitter while

fawns are usually hiding close to the ground with a weaker transmitter and quite commonly next to objects that may interfere with the tracking.

4.4 Conclusions and perspectives

These results are original in the sense of being the first report of what determines the home range size of neonate roe deer. Overall, the results showed that site, roe deer density, fox density, mean temperature in June, and the mother's home range size, likely represent important drivers of a fawn's home range size. There is also a tendency suggesting that the proportion of agricultural area has an impact.

Further studies should focus on investigating fawn habitat use in relation to the home range size and movements, which would be a better estimate of how the fawn perceive and react to landscape features than only the proportion of agricultural area present in the home range as considered in this thesis. This, in combination of quantifying number of hiding places could provide more information regarding the characteristics of home range sizes favourable in different areas. The importance of hiding places has already been connected to fawn survival (Van Moorter et al., 2009), and would therefore be an interesting topic to pursue.

An aim should also be to investigate the connection between fawns and their mothers further since, even though there was a correlation between a fawn's and a mother's home range, the sample size in this study was relatively low. It would also be interesting to look at the evolution of the home range size from birth to adult since habitat use differ heavily between beginning of May to the first of July (Linnell et al., 2004). Due to the low number of positions in this study, I could not divide the home ranges into different ages. I suggest that it would either be useful to use GPS-collars on fawns as well if collars are low enough in weight, or to put more effort in the triangulation. In that way one will get more data for the same period and could include evening and night activity in the analysis as well. Since roe deer generally show a crepuscular activity pattern (Pagon et al., 2013) and most of the triangulation was performed during daytime, it might be favourable to include more positions covering both day and night for a more accurate home range size estimation.

As a summary, this thesis provides new knowledge to the field of roe deer ecology, specifically in the spatial behaviour of roe deer fawns and the connection with their mothers in two contrasting landscapes. The two study areas, Grimsö and Bogesund, show the differences in neonate roe deer home range size between different intraspecific densities, fox abundance, and environmental variables. This new knowledge of roe deer fawns can be included in future method developments of management plans, research studies, and as a basis in the decision-making processes regarding wildlife. When knowing that the spatial use of fawns is similar

as for adults and that they are affected in the same manner, this results in further knowledge useful for investigating actual browsing pressure and food availability for predators on both a local and a larger scale. It also provides more details regarding the variation in the distribution of roe deer, which may be favourable regarding in the use and development of density estimates. This is important since density estimates are a basis in wildlife management with regards to hunting pressure and wildlife accidents.

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Acknowledgements

I would like to give a big thanks to my main supervisor Petter Kjellander for his quick and knowledgeable responses to when my own thoughts were more confusing than clear. His guidance throughout this thesis have enabled both my independent learning experience by dropping of clues but also pushed me over bumps when necessary. His skill as a walking mind map is both amazing and appreciated. The path I have entered is owing a lot to you.

Another person to whom I am in great debt is the never-ending patience of my "technical" supervisor Nadège Bonnot of my also never-ending questions. Without you, the long process of this thesis would have been stretched even further. The long days with you in both offices and homes have helped show me the real face of the loving world called science. I will never forget the amount of help you have laid down for me and my work. I am very grateful.

My assistant supervisors, Ulrika Alm Bergvall and Anders Jarnemo, have also contributed a lot to the implementation of this thesis. When sending a question to Anders, one gets a novel back and for that I am overly grateful. You are a big reason for why the topic of this thesis gained ground and your thoughts set a start to my own development as a master's student. Ulrika, you and Madeleine Christenssons contribution in the making of the age-estimation of the fawns have helped me a great deal with a difficult estimation. Your many and quick email replies have eased a lot of my work and I am glad that I had you at the other end.

Madeleine, the dream field assistant who have always been there for us students and the work with during this summer will always be a very warm and happy memory. Not to mention everything you helped me with afterwards, I am very happy of your structure of the data which helped my process in the start.

Some more people from this past summer that I will always be thankful for are Malin Teräväinen, Linda Höglund, Lars Jäderberg, and the whole RåFäst-team of 2016. Thanks for all the help and a dreamy summer. Even after, Malin, Linda, and Lars, all three of you have always been fast in lending me a hand and answering questions. It has been a huge help.

Malin Aronsson. I may almost (*almost*) say that I would probably still be struggling with my home ranges without your support. That you took the time for me is a thing that I will never forget. It really helped and cleared up a lot for me, you are a life-saver. Cheers!

Due to the many methods included in this thesis I owe a big thanks to Gunnar Jansson (SITES) who guided me through the jungle of pellet counts and calculations, Guilloume Chapron who expertly led me to the helpful packages in R which enabled my triangulation calculation, and of course, Anders Jäderberg who's

technical support and storage of computers was a blessing when my Macbook failed me.

I would like to thank my opponent Heidi Rautiainen, who has provided some emotional support, expert conversations, and company through the many stages of this thesis. The accompanying of another master's student is of great support in a process like this, as well by Chiara Bertacco who has assisted me in many things.

Lastly, but not least, I want to thank all my fellow biologist students who have been my rocks, my sled, my fireworks, and my pillows during this wonderful time.

Appendix 1

Site-specific model selection tables with fox index instead of roe deer index.

Table 1A. *Model selection table on candidate models (Models) of the LMM analysis explaining home range size including the site-specific variables Fox Index and Mean Temp together with number of parameters (K), log likelihood estimate (logLik), corrected Akaike's Information Criterion (AIC_c), Akaike's Information Criterion (ΔAIC), and weights of models (ω). Selected model is highlighted in bold*

Models	K	logLik	AIC_c	ΔAIC	ω
Fox + Mean Temp + Year	**8**	**4.95**	**7.85**	**0.00**	**0.23**
Fox + %Agr + Mean Temp + Year	9	6.15	7.92	0.07	0.22

Table 1B. *Model-averaged estimates for each explanatory variable (Variable) including relative effects (Estimate), standard error (SE), adjusted standard error (Adjusted SE), z value (z), and p-value (p, significance highlighted in bold)*

Variable	Estimate	SE	Adjusted SE	z	*p*
(Intercept)	8.186	0.724	0.734	11.148	<0.0001
Fox	-1.802	0.417	0.423	4.260	**0.00002**
Mean Temp	-0.234	0.049	0.05	4.693	**0.000003**
Year 2014	-0.375	0.135	0.137	2.730	**0.006**
Year 2015	-0.54	0.138	0.14	3.852	**0.0001**
Year 2016	-0.208	0.138	0.14	1.483	0.138
% Agr	-0.291	0.189	0.191	1.520	0.128
Mean Tick Res	-0.003	0.008	0.008	0.356	0.722
Age	0.002	0.005	0.005	0.441	0.66
Mean Birth Kg	0.015	0.043	0.044	0.342	0.732

Table 1C. *The relative importance (Importance) of each variable and the number of models the variable is included in (N models 128, N individuals = 91)*

Variable	Fox	Mean Temp	Year	% Agr	Mean Tick Res	Age	Mean Birth Kg
Importance	1.00	1.00	0.99	0.48	0.24	0.23	0.23
No of models	64	64	64	64	64	64	64

Table 2A. *Model selection table on candidate models (Models) of the LMM analysis explaining home range size including the mother quality variables and Fox Index together with number of parameters (K), log likelihood estimate (logLik), corrected Akaike's Information Criterion (AIC_c), Akaike's Information Criterion (ΔAIC), and weights of models (ω). Selected model is highlighted in bold*

Models	K	logLik	AIC_c	ΔAIC	ω
Mother HR Size	**4**	**2.04**	**7.25**	**0.00**	**0.23**
Fox	4	1.17	8.98	1.73	0.09
(Null)	3	-0.67	9.18	1.93	0.09

Table 2B. *Model-averaged estimates for each explanatory variable (Variable) including relative effects (Estimate), standard error (SE), adjusted standard error (Adjusted SE), z value (z), and p-value (p, significance highlighted in bold)*

Variable	Estimate	SE	Adjusted SE	z	*p*
(Intercept)	5.404	2.137	2.203	2.453	0.014
Mother HR size	0.004	0.002	0.002	2.070	**0.038**
Fox	-0.469	0.262	0.284	1.656	0.098
Mother Body Mass	-0.04	0.051	0.054	0.729	0.466
Age	-0.051	0.055	0.058	0.882	0.378
Mean Birth Kg	0.065	0.102	0.112	0.579	0.563
Mother Age	-0.004	0.038	0.042	0.086	0.932
Year 2014	0.188	0.345	0.361	0.522	0.602
Year 2015	0.649	0.387	0.403	1.609	0.108
Year 2016	-0.012	0.332	0.35	0.035	0.972

Table 2C. *The relative importance (Importance) of each variable and the number of models the variable is included in (N models = 128, N individuals = 17)*

Variable	Mother HR Size	Fox	Age	Mother Weight	Mean Birth Kg	Mother Age	Year
Importance	0.5	0.38	0.19	0.16	0.13	0.11	0.04
No of models	64	64	64	64	64	64	64

Table 3A. *Model selection table on candidate models (Models) of the LMM analysis explaining daily average movement including the site-specific variables Fox Index and Mean Temp together with number of parameters (K), log likelihood estimate (logLik), corrected Akaike's Information Criterion (AIC_c), Akaike's Information Criterion (ΔAIC), and weights of models (ω). Selected model is highlighted in bold*

Models	K	logLik	AIC_c	ΔAIC	ω
Fox + Mean Temp + Year	8	-731.37	1480.07	0.00	0.07
Fox + Mean Temp + Mean Tick Res + Year	9	-730.53	1480.73	0.66	0.05
Fox + Year	**7**	**-732.89**	**1480.79**	**0.72**	**0.05**
Mean Temp + Year	7	-732.94	1480.89	0.82	0.05
Mean Temp + Mean Tick Res + Year	8	-731.81	1480.93	0.86	0.05
Fox + Mean Birth Kg + Mean Temp + Mean Tick Res + Year	10	-729.67	1481.39	1.32	0.04
Fox + Mean Birth Kg + Mean Temp + Year	9	-730.96	1481.60	1.53	0.03
Fox + Mean Birth Kg + Year	8	-732.19	1481.70	1.63	0.03
Mean Birth Kg + Mean Temp + Mean Tick Res + Year	9	-731.12	1481.90	1.83	0.03
Fox + Mean Temp + Sex + Year	9	-731.18	1482.04	1.97	0.03
Fox + Mean Tick Res + Year	8	-732.36	1482.05	1.98	0.03
Fox + Mean Birth Kg + Mean Tick Res + Year	9	-731.19	1482.05	1.98	0.03

Table 3B. *Model-averaged estimates for each explanatory variable (Variable) including relative effects (Estimate), standard error (SE), adjusted standard error (Adjusted SE), z value (z), and p-value (p, significance highlighted in bold)*

Variable	Estimate	SE	Adjusted SE	z	*p*
(Intercept)	923.514	380.172	381.835	2.419	0.016
Fox	-366.799	189.69	191.403	1.916	0.055
Mean Temp	-43.304	22.062	22.271	1.944	0.052
Year 2014	-6.121	49.301	49.759	0.123	0.902
Year 2015	-122.654	55.309	55.75	2.200	**0.028**
Year 2016	-99.807	47.845	48.324	2.065	**0.039**
Mean Tick Res	5.088	3.449	3.486	1.46	0.144
Mean Birth Kg	21.206	19.279	19.479	1.089	0.276
Sex (M)	-15.142	22.401	22.649	0.669	0.504
Age	-0.313	0.98	0.991	0.316	0.752

Table 3C. *The relative importance (Importance) of each variable and the number of models the variable is included in (N models = 128, N individuals = 118)*

Variable	**Fox**	**Mean Temp**	**Year**	**Mean Tick Res**	**Mean Birth Kg**	**Sex**	**Age**
Importance	0.93	0.68	0.67	0.47	0.37	0.28	0.25
No of models	64	64	64	64	64	64	64

Table 4A. *Model selection table on candidate models (Models) of the LMM analysis explaining daily average movement including the mother quality variables and Fox Index together with number of parameters (K), log likelihood estimate (logLik), corrected Akaike's Information Criterion (AIC_c), Akaike's Information Criterion (ΔAIC), and weights of models (ω). Selected model is highlighted in bold*

Models	K	logLik	AIC_c	ΔAIC	ω
(Null)	3	-143.20	293.67	0.00	0.18
Mother Age	4	-142.11	294.45	0.78	0.13
Age	4	-142.55	295.32	1.64	0.08

Table 4B. *Model-averaged estimates for each explanatory variable (Variable) including relative effects (Estimate), standard error (SE), adjusted standard error (Adjusted SE), z value (z), and p-value (p, significance highlighted in bold)*

Variable	Estimate	SE	Adjusted SE	z	*p*
(Intercept)	464.11	244.464	255.99	1.813	0.07
Mother Age	-16.8	11.234	12.034	1.396	0.163
Age	4.844	3.3	3.537	1.370	0.171
DAM Mother	-0.165	0.227	0.242	0.681	0.496
Fox	-46.107	89.826	95.98	0.480	0.631
Mean Birth Kg	-7.242	51.266	54.908	0.132	0.895
Mother Body Mass	1.174	13.021	13.931	0.084	0.933
Year 2014	-33.642	96.564	102.874	0.327	0.744
Year 2015	-73.523	90.568	97.121	0.757	0.449
Year 2016	-137.148	82.301	88.783	1.545	0.122

Table 4C. *The relative importance (Importance) of each variable and the number of models the variable is included in (N models = 128, N individuals= 23)*

Variable	Mother Age	Age	DAM Mother	Fox	Mother Body Mass	Mean Birth Kg	Year
Importance	0.36	0.27	0.21	0.18	0.16	0.16	0.01
No of models	64	64	64	64	64	64	64